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RADIATION EXPOSURE OVERVIEW

Microwave Ovens and the Public

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Radiation Exposure Overview
Microwave Ovens
And The Public

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FOREWORD

The significance of a specific source of radiation and whether efforts directed towards its control are effective depend, in large part, on an assessment of the magnitude of radiation exposure received by a population from that source. The process of assessment includes comparing estimates of exposure against pertinent guidance or standards. These comparisons provide reference points for radiation control programs.

Radiation exposure overviews are designed both to highlight these points of reference as well as identify needed information. Developed from available, salient information, each overview seeks to relate an observed or potential radiation experience or exposure of a population group with a radiation source. Relevant guidance or standards, and the status of exposure control efforts, where such data are available, are also incorporated.

Radiation exposure overviews are prepared by the Office of Criteria and Standards with the assistance of the Divisions and Offices of the Bureau of Radiological Health.

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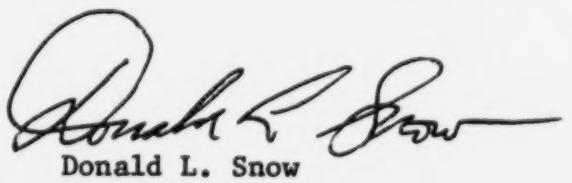
PREFACE

This overview focuses on the radiation exposure of users of microwave ovens. Possible hazards associated with this exposure and general control activities needed for further reducing the potential for radiation effects are singled out.

The readers of this report will observe that the body of data specific to radiation emission from microwave ovens is limited and much more information is needed. This is a reflection, in part, that these new electronic products are only beginning to emerge in commercial places and households throughout this country.

The authors are members of the Standards Services Branch of the Office of Criteria and Standards.



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MICROWAVE OVENS AND THE PUBLIC

INTRODUCTION

A source of potential microwave radiation exposure to the general population is the microwave oven, which consists of a microwave-generating magnetron tube, a waveguide to direct the radiation to the cooking chamber and a mixer to distribute the radiation throughout the chamber. In 1968, total sales of all types of microwave ovens were projected at about 40,000 units per year (1). If the price of consumer units were to drop to $250, from the current price range of $500 to $1,000 per unit, sales might exceed 500,000 per year (1). Microwave ovens are currently available from fewer than a dozen domestic and foreign manufacturers, but additional industrial firms have indicated their probable entry into this market.

Biological research and military and occupational experience with microwave radiation have indicated that microwave exposure can cause serious bioeffects when conditions of use are not controlled (See Appendix A). The increasing use of this source of energy for applications other than those of the military and industry, particularly in consumer products, warrants the study of the potential hazard to the population. It is anticipated that the population that would be affected by the increased availability of microwave ovens would be the individual owners of home ovens, patrons of commercial facilities, and employees of food service establishments. From the information presented in this overview, the need for additional study and analysis of this subject is clearly indicated.

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RADIATION EXPERIENCE

EXPOSURE ESTIMATES

The microwave radiation exposure received by individuals from commercial, public, and private utilization of microwave ovens is not yet clearly defined, particularly with respect to type of risk and exposure times for members of the public. The only current indications of the degree and extent of possible exposure are the results of limited field surveys of microwave oven units, almost all of which were located in commercial or food service establishments. In many cases, these same ovens with only slight modifications could be used in the home. Investigation of these units to determine the leakage of microwave radiation during both normal and improper operation, in terms of power density (milliwatts per square centimeter, mW/cm^2), has indicated that the potential for human exposures from these devices does exist.

The Federal Communications Commission has designated the following frequencies for unlicensed use in industrial, scientific, and medical equipment (2):

13.56 MHz $\pm$ 6.78 kHz[1]	915 MHz $\pm$ 25 MHz
27.12 MHz $\pm$ 160 kHz	2450 MHz $\pm$ 50 MHz
40.68 MHz $\pm$ 20 kHz	5800 MHz $\pm$ 75 MHz
	22125 MHz $\pm$ 125 MHz

Microwave ovens, which fall into this category, are operated generally at frequencies of 915 and 2450 MHz. The operating frequency for all ovens in the investigations that specified such information was 2450 MHz.

Field Surveys

At present, a performance standard[1] specifically applicable to microwave ovens, promulgated by an authoritative standards-setting organization, does not exist. However, in order to intercompare survey results, a radiation emission of 10 mW/cm^2 will be used as a reference value because of its relationship to existing guidance for sources and situations other than microwave ovens (3-6).

The results of a number of surveys reported in the literature are summarized in table 1. These results represent measurements made with either water or food placed in the oven to simulate actual operating conditions. The microwave emissions occurred at the periphery of the oven door due either to leakage through the door seal or conditions which prevented the doors from closing completely. The surveys noted in table 1 included 494 units of which 109 units or ~22 percent emitted levels of radiation greater than 10 mW/cm^2 under normal operating conditions.

Laboratory Investigations

In addition to the potential leakage from microwave ovens resulting under normal operating conditions, a second potentially serious exposure hazard exists if safety features are either circumvented or fail.

In a recent investigation, the Public Health Service (20) examined the type of safety interlock switches on four models of home microwave ovens and one commercial model, the manner in which they could be purposely bypassed, and the potential exposures that would result from such actions. Also studied was the radiation leakage that could be expected if microwave energy seals on the doors of the ovens failed

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[1]Term defined in the glossary.

Table 1. Exposure levels observed in microwave oven surveys

Organization (locations)	Date	Use	Detecting instrument
University of Washington, (unspecified locations) (7)	1963	Food establishments	Model NF-157 Power Density Meter and RF Pickup Probe PR-2-157
Pennsylvania Department of Health (Northwestern Pennsylvania) (8)	1965	Food-service establishments	Sperry Model B86B2
National Center for Urban and Industrial Health (Colorado, Oregon, Nevada and New Mexico) (9)	1966-continuing	Commercial establishments, restaurants, appliance stores, food markets, kitchens, self-service cafeterias, and private residences	Ramcor Model 1200 Densiometer
U.S. Army, Environmental Hygiene Agency (Fort George G. Meade) (10,11)	Feb. 1967 Sept. 1967 (resurvey)	NCO Club and officers mess	Ramcor Model 1200 Densiometer
U.S. Army, Environmental Hygiene Agency (Walter Reed Army Medical Center) (12)	Sept. 1967	Military hospital	Ramcor Model 1200
U.S. Army, Environmental Hygiene Agency (Walter Reed Army Medical Center) (13)	March 1968	Military hospital	Ramcor Model 1200 Densiometer
Pinellas County Health Department (Pinellas County, Florida) (14)	Feb. 1968	Public and private facilities	Ramcor Model 1200 Densiometer
U.S. Army Environmental Hygiene Agency (Army European Exchange System, Germany and England) (15)	Apr-May 1968	Variety of uses at U.S. installations	Ramcor Model 1200 Densiometer
Dept. of Public Health, District of Columbia (Washington, D.C.) (16)	June-Aug 1968	Restaurants and snack bars	Ramcor Model 1200 Densiometer
U.S. Public Health Service and Alabama State Dept. of Public Health (Montgomery, Alabama) (17)	1968	Hospital, employees lounge, snack bars, and military installation	Ramcor Model 1200B Densiometer
U.S. Public Health Service and New York City Health Dept. (New York City) (18)	Oct. 1968	Hospital	Ramcor Model 1200B Densiometer
U.S. Public Health Service and Delaware State Dept. of Health (Wilmington, Del.) (19)	Feb. 1969	Restaurants, snack bars, and private residences	Ramcor Model 1200B Densiometer

[a] This statement applies to only 76 of the 118 units tested (9), but is included as an indication of the maximum observed exposure level.

Table 1. Exposure levels observed in microwave oven surveys (continued)

	Number of units	Measured leakage levels: Number of units >10 mW/cm^2	Measured leakage levels: Maximum level observed (mW/cm^2)	Measured leakage levels: Measurement distance (cm)
Unspecified	9	1	50	Unspecified
Hinged door	14	1	12	5 to 7.6
Vertical sliding door	10	0	0	5 to 7.6
Hinged door	93	27	The distance needed to reduce these exposures to 10 mW/cm^2 ranged from 0.5-12 inches[a]	Surface
Vertical sliding door (Various models of Tappan, Litton, and Raytheon)	25	1		
Litton	2	0	8	2.5
Raytheon	1	1	200	5 to 13
Speedrange, Model 110C	30	4	25	5 to 13
Various models of Speedrange, Litton, Mark V, and Signature	38	6	20	5 to 13
Various models of Litton, Raytheon, and Tappan	42	[b]15	Not given	up to 15 to 30
Various models of Litton, Raytheon and Tappan	16	9	200	5 to 13
Unspecified variety of models	187	37	80	2.5 to 5
Hinged	3	2	20	1.3 to 6.3
Vertical sliding	1	0	0	Unspecified
Sliding 45° angle	1	1	20	contact
Hinged	1	1	40	5
Litton, Raytheon, Westinghouse, G.E., and Tappan	21	3	20	5

[b] This figure represents the number of units with leakage radiation ≥10 mW/cm^2, since the data reported could not be revised to parallel numbers of units >10 mW/cm^2 as reported in other surveys.

or were worn. All measurements were made using a Ramcor 1200 B Densiometer with a load of 250 milliliters of water in the oven. These measurements demonstrated that power densities exceeding 700 mW/cm^2 could be produced in front of the oven if the door safety interlocks failed or were defeated and the door was wide open. A separation distance of 120 cm between the detecting instrument and the open door was often insufficient to lower the power density level to 10 mW/cm^2. In the tests that simulated failure of the door seals, levels of 10 mW/cm^2 or greater were observed for some of the ovens at 5 cm from the door; this was similar to the observations made in field surveys when door seals were worn. The investigators noted that there were no warning mechanisms in the ovens to alert an operator of an interlock failure.

BIOEFFECTS

Laboratory, field, industrial and military experience has shown that certain bioeffects in humans result from microwave exposure from sources other than microwave ovens, such as radar. Depending on the frequency of the radiation and the time of exposure, bioeffects reported in humans from microwave exposure at power density levels on the order of several mW/cm^2 to several hundred mW/cm^2 include temporary sterility in males (21), eye cataracts (22-25) and blood changes (26), although the latter findings were described by the investigators as "paradoxical and difficult to interpret." Bioeffects reported at levels of tenths of 1 mw/cm^2 include periodic headaches (27, 28), abnormal slowing of the heartbeat (27, 28), and disturbances in the neural system (27, 28). Also, a statistically significant number of fathers of mongolism cases had prior exposures to radar during military service (29). No data on the levels of radar exposures were included in this study. A summary table of observed human bioeffects is given in appendix A for background information.

There is one report in the literature describing possible bioeffects from microwaves emanating from microwave ovens. It describes the medical history of a microwave oven repairman, who had a recurrent, blotchy, hemorrhagic eruption on his abdomen and thigh. The condition was histologically an angiitis (vasculitis) (30). While not definitely attributed to microwave radiation, it is the only medical and physical finding reported in the open literature that suggested a possible causal role of microwave energy from microwave ovens.

EXPOSURE CONTROL

RECOMMENDATIONS, STANDARDS AND REGULATIONS

Standards have been developed by various organizations for limiting exposures from microwave equipment used in scientific, medical, industrial, and military applications. These standards generally relate to occupationally exposed personnel. Representative standards for continuous exposure are compiled in table 2. To date, a standard specifically for exposure from microwave ovens has not been promulgated.

Table 2. Summary of current representative microwave exposure standards for continuous exposure

Organization	Exposure standard (mW/cm^2)	Date of publication	Basis - Comment
USASI (6)	10	1966	Available knowledge and due consideration of tolerable rise in tissue temperature (6)
U.S. Air Force (3) U.S. Army (4) U.S. Navy (5)	10	1966 1965 1966	Heat tolerance and transfer capabilities of the human body as calculated by Schwann (31)
Czechoslovakia (32)	.025	1968	For continuous generation-average energy flow during 8-hour working day for occupationally exposed
	.0025	1968	For continuous generation-average energy flow for 24-hour exposure time of the general population
U.S.S.R. (33)	0.01	1958	Consideration of "disruptions of the functional state of the neural and cardiovascular systems" (33)

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COMPLIANCE

The recent passage by Congress of the Radiation Control for Health and Safety Act of 1968 (34) provides for the Secretary of Health, Education, and Welfare to prescribe performance standards for the control of emissions from electronic products when it is determined that standards are necessary for public health protection. The manufacturer would be required to certify that each product for which a standard has been established conforms to the law. In addition, if a manufacturer produces an electronic product which contains any defect relating to the safety of use of such products, the manufacturer has the responsibility to notify the Secretary of the Department of Health, Education, and Welfare of this defect. The law also provides for reports to Congress by the Secretary on studies of State and Federal programs to control hazards associated with electronic products.

Two states, Louisiana and Arkansas, have passed laws (35,36) authorizing the control of the use of non-ionizing radiation. Under the provision of the Louisiana law, the Louisiana State Board of Nuclear Energy has authority to require registration or licensing of sources of radiation which it deems to constitute a risk to occupational and public health and safety. The Arkansas law enables the State Board of Health to establish rules and regulations concerning non-ionizing radiation.

To date, specific performance standards as authorized by the Radiation Control for Health and Safety Act of 1968 have not been established. The legislation noted, however, provides the framework for promulgation of standards when needed and provides for the determination of compliance to such standards.

Analysis and Comments

Radiation Experience

Exposure Levels

Microwave radiation emitted at the periphery of the doors and the spaces where the door grill meets the door frame is considered a directional narrow beam. Leakage levels noted in table 1 were generally limited to the periphery of the door seal. However, comments of the investigators indicated that additional important potential causes of high leakage power densities were worn door spacers, failure of interlocks, ovens operating with partially open doors, and ovens operating with completely open doors in which the interlocks were purposely disconnected. Emissions from an open door would have broad-beam characteristics and could result in whole-body exposure.

Factors other than power density levels that contribute to an estimate of exposure are the location of the units in relation to the individuals at risk and the duration of exposure. Most ovens are installed on counters or built as console units at comparable heights and would tend to expose the upper part of the body. The operation of these ovens is usually intermittent, and the use of the ovens by patrons of self-service food facilities would generally result in short periods of exposure. However, these latter factors of individual risk and exposure times have not been explored. Based on the survey information presented earlier, table 3 summarizes various types of exposure situations and the microwave emission levels that could be expected.

The limitations of the instrumentation must be considered when evaluating such survey data. Horn antennas designed and calibrated

Table 3. Summary of emission levels observed for microwave ovens under various exposure situations

Exposure situation	Emission level at ∿ 5 cm (mW/cm^2)
Normal use and conditions, no defects	10
Normal use and conditions, leakage through door seals	10 10 - 200 (range)
Worst conditions (experimental), totally defeated interlocks	700

for far field[2] measurements have serious limitations when measurement of the near field[3] is attempted. Power density variation is extreme in this region since the source antenna does not approximate a point source and wave fronts approach the antenna from different angles, resulting in interaction in either an additive or subtractive manner, as a function of their relative phase. In addition, an individual wave front appears to a large aperture horn to be a curved, rather than plane wave, causing phase substraction. These effects made interpretation of near field measurements made with these instruments very uncertain. Although not necessarily stated in the reports, much of the data reviewed was taken under near field conditions.

The environment in which a microwave oven is located can have a significant effect upon the power density pattern surrounding the oven. Reflected waves, primarily from metal surfaces, can interact with the direct radiation to cause an irregular power density pattern in what would normally be the far field. This interaction may result in addition of the direct and reflected beams, creating power densities in certain locations that are several times greater than would be present if the oven were in an anechoic environment. The magnitude of the increase is a function of the number and proximity of reflective surfaces present around the oven.

A proposed standard of the USASI C95 committee outlines general procedures for measurement of microwave power densities, part of which can be applied to microwave oven surveys. These include:

a. Evaluation of source from standpoint of personnel hazard potential, and;
b. Planning and conducting a comprehensive survey of potential hazard areas.

[2,3] Terms defined in the glossary.

The survey procedure should include scanning the field under consideration, conducting performance checks and adjustments on the instrument, determining the presence and identification of interfering radiofrequency fields, and determining the presence of reflecting surfaces which may cause an increase in power density.

A proposal for modifying the USASI standard for microwave exposure (USASI C95.1-1966) has recently appeared in the literature (37).

The USASI standard states that the "Radiation Protection Guide (RPG)"[4] number (10 mW/cm^2) should be appropriately reduced under conditions of moderate to severe heat stress, however, it gives no quantitative method for doing so.

Mumford has proposed that this reduction be a function of the environment as measured by the temperature-humidity-index (THI). Under the conditions of this proposal, the "RPG" would be as follows:

When the THI is 70 or less, "RPG" = 10 mW/cm^2

When the THI is between 70 and 79, "RPG" = (80 - THI) mW/cm^2

When the THI is 79 and greater, "RPG" = 1 mW/cm^2.

Bioeffects

Certain human bioeffects from microwaves reported by Soviet and other Eastern European investigators have not been corroborated by Western scientists. Although these were the result of radar exposure or special laboratory studies, similar effects might occur after exposure to microwaves emanating from microwave ovens. These effects include periodic headaches, neural disorders and abnormal slowing of the heartbeat, and were noted at very low radiation intensities. Adequate reporting is needed in this area in order to evaluate and delineate the validity and import of these effects.

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[4] Defined in USASI C95.1

Research is also needed to evaluate the possible cumulative bioeffects from microwave exposure. There is no experimental evidence to substantiate or define the existence or nonexistence of cumulative effects from subthreshold exposures, nor, in fact, the existence of a "threshold level." An exception is that exposures to the eye below a certain exposure level are assumed to be noncumulative (23-25).

Another area of concern is the theoretical definition of "exposure" and "dose", if such a distinction can be made. This would include bioeffects comparisons, possibly analogous to studies in radiobiology, in which the relative biological effectiveness (RBE) concept is employed. Research which helps correlate microwave frequency with the degree and type of bioeffects in humans and experimental animals should be performed. If necessary, this knowledge can then be applied to setting varying exposure standards depending on frequency.

EXPOSURE CONTROL

A philosophy of acceptable exposure of the general population to microwave radiation needs to be developed. In addition, source-oriented standards must reflect the potential hazards to the various user populations. The reasoning used by the Federal Radiation Council (38) in developing its Radiation Protection Guides for ionizing radiation may be a useful approach. Factors considered by the Council included population groups exposed, history of exposure, time for bioeffects to become manifested, health of the exposed population, knowledge of risk involved and the genetic risk to future generations.

Those aspects of microwave exposure for which standards and recommendations can be developed suggest the microwave radiation exposure control categories presented in table 4. The status of standards and recommendations related to such control is discussed

Table 4. Status of standards and compliance in the microwave radiation exposure control categories

Exposure Control Categories	Status
Basic Exposure Guidance	Guidance concerning microwave exposure has been based on the heat transfer capacity of the human body and on non-heat related physiological effects. In this guidance, great care is urged when the possibility exists of exposure to levels higher than those recommended. No emphasis, however, is given to avoiding exposure which does not exceed the applicable maximum levels.
Equipment Design	Emphasis is being given to the design of microwave ovens so that, in normal operation, they do not emit leakage radiation in excess of the applicable standard. It appears that faulty design has been a major reason for many of the high levels of leakage reported in this paper.
Equipment Monitoring	Since leakage from microwave ovens may change with use, a routine monitoring program should be useful. At present no State has a program for periodic monitoring of microwave ovens. Standardization of monitoring equipment and procedures is lacking.
Operator or Population Awareness	Many users of microwave ovens are not aware of the potential hazards of exposure to microwave radiation. The extent to which the user population is aware of the potential hazard has not been evaluated. Presently, manufacturers have not provided warnings of the potential hazards of microwave ovens.

for each category.

CONCLUSIONS

The following activities are identified as having potential for further reducing exposure to the population from microwave ovens or in providing further definition of exposure:

1. Development of performance standards for emission levels from microwave ovens, based on the affected population groups.
2. Development and standardization of instruments and measurement techniques for the detection of near field microwave radiation, including determination of emission patterns.
3. Survey of the distribution of microwave ovens and measurement of the factors which determine actual user exposure, specifically through local surveys of number, location, and usage of microwave oven units.
4. Implementation of routine surveys to monitor microwave devices which have been in use for a period of time.
5. Educational and information programs for microwave oven repairmen and microwave oven owners as to the potential hazards associated with malfunctioning or incorrectly used ovens.
6. Research directed to all the potential biological effects of microwave radiation, both somatic and genetic, including definition of differences between incident microwave radiation and effective energy absorbed, the effect of microwave frequency in the production of biological damage, and the determination of whether or not threshold exposures exist for the various effects produced by microwaves.
7. Development of improved microwave oven designs that eliminate excessive microwave radiation leakage around the oven door and provide a fail-safe interlock system.

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GLOSSARY

1. Microwaves - nonionizing electromagnetic radiation with a frequency range of 30-300,000 MHz.

2. Hertz (Hz) - the unit of frequency; one hertz is 1 cycle/second
   Megahertz (MHz) - 10^6 hertz.
   Kilohertz (kHz) - 10^3 hertz.

3. Power Density - energy rate per unit area of microwave radiation expressed in milliwatts per square centimeter (mW/cm^2).

4. Near Field - the area relatively close to a microwave source where the average power density remains relatively constant with distance and the wave front is characterized by extreme field curvature and power density variation.

5. Far Field - the area beyond the near field where the wave front is planar and the average power density decreases with the inverse square of the distance. The distance from the source at which the far field begins depends on the shape and size of the source and hence cannot be defined for microwave ovens.

6. Magnetron - a diode vacuum tube in which the flow of electrons is controlled by an externally applied magnetic field to generate power at microwave frequencies.

7. Radiofrequency - An electromagnetic wave frequency between 3 kHz to 3×10^5 MHz.

8. Performance Standard - a statement requiring a certain set of conditions to be fulfilled by stating the results which must be achieved by whatever method is used and may be legally enforceable.

9. <u>Temperature-Humidity-Index (THI)</u> - a measure of the heat stress on an individual due to the environment expressed mathematically as follows:

$$THI = 0.72(t_d + t_w) + 40.6$$

where t_d is the dry-bulb temperature in degrees Centigrade and t_w is the wet-bulb temperature in degrees Centigrade.

APPENDIX A. Summary of Reported Studies Concerning Bioeffects in Humans from Microwave Radiation

Subject(s)	Frequency (MHz) and Source	Level	Exposure History	Observed Effects
Worker in microwave environs (22)	unspecified, microwave generator	average-5 mW/cm^2/day; occasionally up to 120 mW/cm^2	occupationally for a year	cataract
Worker in microwave environs (23)	unspecified, radar	350 W/cm^2 to several W/cm^2	unspecified	cataract
Microwave oven repairman (30)	2450, microwave oven	10 mW/cm^2, 22 mW/cm^2 depending on distance	over a period of 5 years (occupationally)	vasculitis (angiitis)
Experimental subjects (39,40)	900, 2456, microwave generator	unspecified	unspecified	heating of deep musculature of the thigh
Workers in microwave environs (26)	2880, 9375, radar	estimated up to 13 mW/cm^2	unspecified	blood cell population changes